Analog Electronic Circuits
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Lecture – 90
Feedback System (Part–A)

So, students welcome back to our online certification course on Analog Electronic Circuits. Myself Pradip Mandal from E and EC department of IIT, Kharagpur. Today's topic of discussion it is Feedback System. So, we shall start with basics and then gradually, we will be moving to practical circuit.

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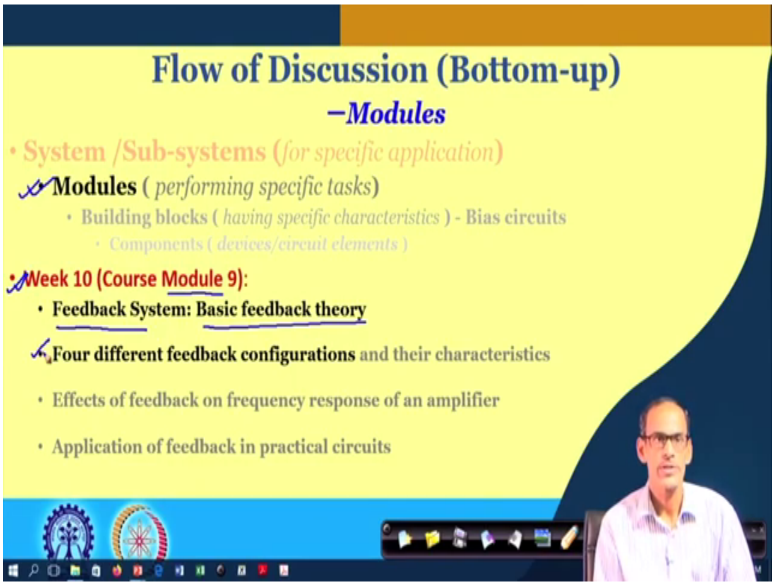

So, the based on our plan overall plan, we are in modules in fact, whatever the concepts we will be talking it is primarily on analog modules and today we are starting this week 20. In fact, it is module 9 and as I said that we are going to talk about feedback system. We are going to start with basic feedback theory. And then today, we will be able to cover four different basic configurations of feedback system. In fact, four different basic configurations of feedback systems we will be discussing.

And this four basic configurations are generic enough, it can be deployed in other configurations as well.

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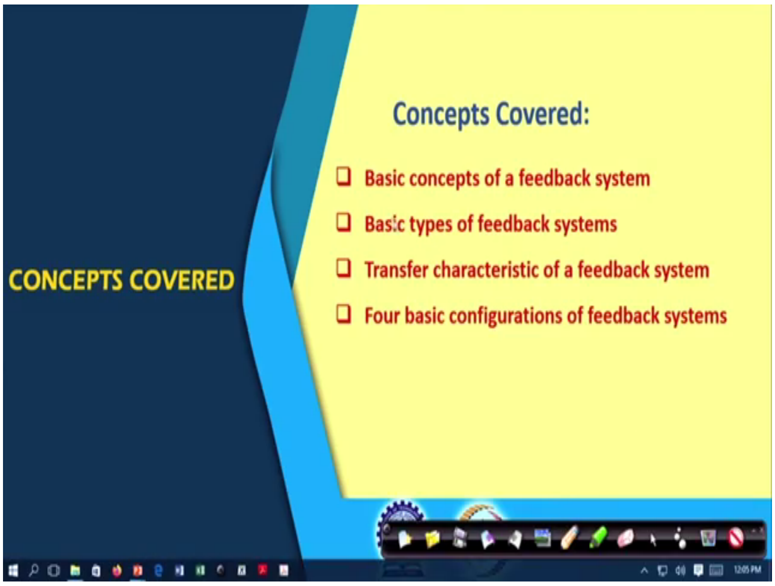

So, the concepts we are planning to cover today, it is the we shall starts from basics of feedback system. And then, we shall talk about types of feedback systems, basic types of feedback system and then we shall derive transfer characteristic of feedback system. And then we will be focusing on four different distinct configurations of feedback systems. To start with the basic concept of feedback system so, far we are talking about amplifiers.

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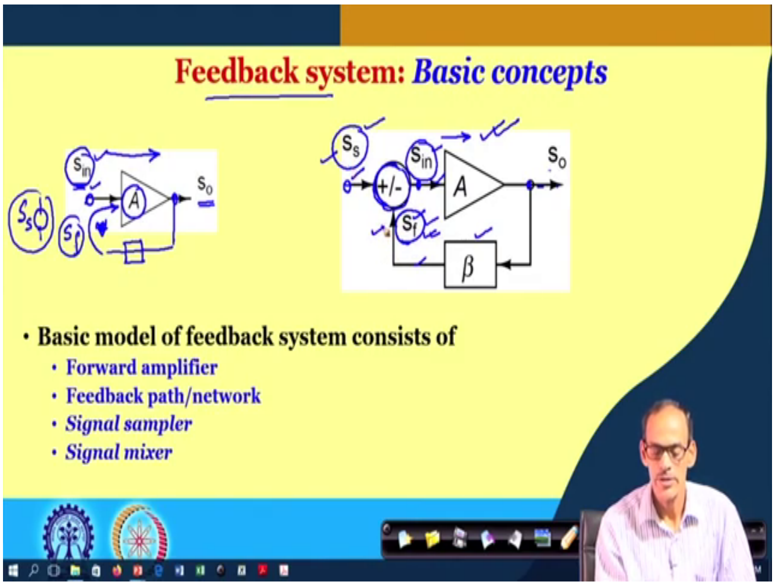

In fact, different amplifier configurations and those amplifiers are essentially linear circuit. So, we can say that at the input, we are applying input signal either it may be in the form of voltage or current. On the other hand at the output, we are observing the corresponding amplified version of the input signal and this A represents the amplification factor.

So, this is the I should say basic model of whatever the amplifier we have discussed. This input need not be single ended, it can be even differential and we know the signal it is propagating from left to right from the input port to the output port. Whenever you are talking about the feedback system, what we are trying to do, we are essentially sampling this signal and part of it we are taking back and we are given to the input.

In fact, while we are taking this feedback signal from the output, we also have to retain the corresponding input port primary port for feeding the signal. So, whatever the feedback signal, we have to generating here, let we call it is say signal f and the primary input we do have say maybe S. So, this signal S and this signal need to be combined together to generate this input signal for the amplifier.

So, if you see the model we use, it is given here from this point to the primary output, we do have the forward amplifier take which is taking the signal from left to right and then part of this signal or maybe this entire signal we are sampling. And then we are generating a part of this signal by this circuit called feedback path or feedback network to generate the feedback signal.

And this feedback signal, we are combining with the primary input signal to generate the input signal of the forward amplifier. So, we required some mixer here to mix this signal and this signal and while you are mixing the signal, we want to retain the linearity only option we are keeping here it is the signal may be coming from this port to this port either in same phase or opposite phase; likewise this signal while it is coming to the input it may have its plus or minus.

So, we can say that this mixer predominantly it is not amplifying or attenuating, it is rather either multiplying with plus 1 or minus 1 and then combining the primary input signal and the feedback signal to generate the input signal for the amplifier. So, that is the basic model of feedback system; this feedback system we will be coming back again and again.

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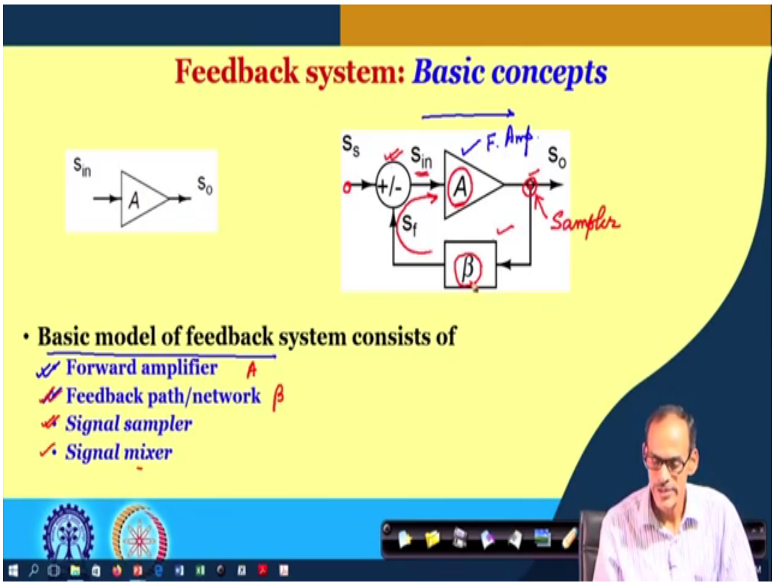

So, if you see this in this feedback system what are the basic modules we do have first of all we do have forward amplifier. So, this is called forward amplifier which is taking the signal from left to right and then we also have feedback path. So, we do have the feedback path here through which, we are taking the primary output and bringing the signal back to the input port of the amplifier. So, we do have the feedback path and its transfer function it is beta for forward amplifier the transfer function it is A.

And then also we do have signal sampler. So, whenever we are tapping this signal, we are calling this is sampler signal sampler and then also we do have signal mixer. So, here we do have the mixer which is mixing the feedback signal along with the primary input to generate the input signal for the amplifier ok.

So, let us talk about more about this feedback system and how we are primarily mixing based on that and also the polarity of the transfer function of the forward amplifier and feedback path. The system can be classified primarily into two types; one is negative feedback system and positive feedback system.

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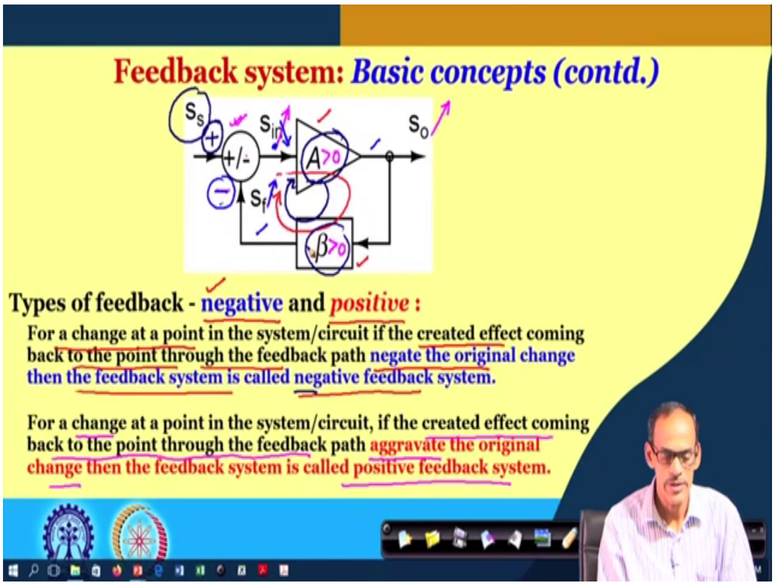

So, what we said is that, the basic types of feedback system it is, we make say it is negative feedback system or positive feedback system. So, when we call it is negative feedback system? Suppose, in first of all it is having a feedback, whether we call it is positive or negative.

So, the signal it is looping around this path which is going through this forward amplifier and also it is going through the feedback path and of course, we do have sampler and mixer. Now, based on the feedback signal coming back, we may call either it is negative or positive and if you see here, when you call it is negative feedback system it is essentially for exchange at a point in the feedback system or circuit.

If the created effect coming backed coming back to the original point through the feedback path. If it negates the original change then the feedback system it is called negative feedback system. Say for example, if I consider say suppose this signal it is getting increased or say this signal at this point it is getting increased. Now, if I assume that A is positive.

So, it is expected that this signal we will also be increasing. If I consider beta it is also positive, then since S naught it is increasing. So, this feedback signal it is also increasing. Now, while it is going through this mixer and if I say that this block this mixer block, it may create positive or negative coefficient. So, suppose this is negative, then whatever the feedback effect we are getting here due to this change and because of this minus sign which is coming back here, it is going in other direction because of this negative sign.

So, since the this effect coming back which is this blue color which is opposing the pink color or negating the original change and hence we call it is negative feedback system. And in fact, this change it may happen at any point in this system need not be only at this point; it may be here or it may be here whatever it is. We can start from a point and then we can see follow the feedback path.

And then we can see whether the feedback signal coming back to the point through the feedback and feedback path and forward amplifier it is negating or not. On the other hand in case if the; signal it is if the change if the created effect due to a change coming back through the feedback path, if it is aggravating the original change; that means, if it is in in the same phase. Then we call the feedback system it is positive feedback system.

Note that it is it is very important that in along according to this definition, the polarity of this signal coming to this amplifier it is immaterial. In many of the textbook you might have seen that invariably, we say this is plus and this is minus and this plus and minus this sign it may be defining negative feedback system. But that is a wrong concept you need to be careful, it is immaterial of this polarity of the primary signal going to the amplifier.

What it is important is that, if you go through this loop and if you follow whatever the signal it is original signal coming back through this feedback loop if it is negating the original change then we call it is negative feedback system. In fact, based on the possible sign here or in fact, based on the sign of A and beta we may have positive and negative feedback systems. So, we will be discussing that in the next slide of different examples, but before that let me summarize what I said is.

In case any change say for example, in case if you have a change here, if it is say if the change is positive and the corresponding effect here it is positive assuming both are plus and then this change it in case if it is having a minus sign in the mixture. So, this is creating a change here in the opposite direction and since A is positive. This blue effect the feedback effect it is countering the original and hence, we call it is negative feedback system.

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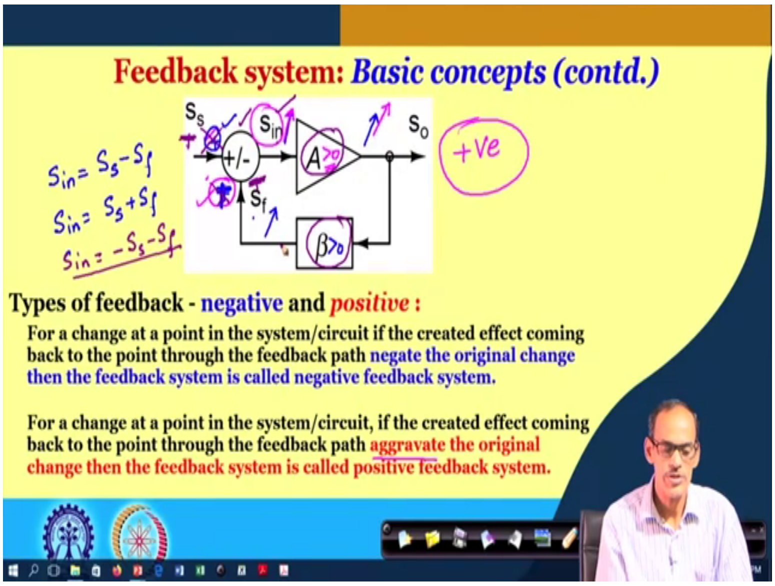

On the other hand, if I if I consider say the same original change here and then the corresponding effect if it is coming back here. And if I say this is plus sign which means that S f and S in they do have the same phase so, which means that the corresponding effect coming back here it is in the same direction and so, the effect coming back through this feedback path it is in the same direction which means that it aggravates the original change and hence because of this plus sign here. Assuming this is also positive the system becomes positive feedback system.

So, as I said that let me consider different cases. So, not only we will be having this sign but also we can think of the flexibility of A can be negative or beta can be negative. So, a various combination and based on the polarity here and here to generate this input signal, we may say that we do have different expressions of the S in which is function of S s and S f. So, suppose we do have S in is equal to S s minus S f, which means that we do have a plus sign here and we do have minus sign here.

On the other hand in case if we do have S in equals to S s plus S f then we can say this is positive and also this is positive. Likewise, in case if I have a situation where S in equals to say minus S s and minus S f which means that both this polarity of this input and polarity of this input of the mixture it is minus sorry minus. This is minus this is also minus.

So, then we can say that S in equals to minus S s minus S f. So, likewise based on the polarity, if we define the relationship among S in and S f and S s from that we can say what may be the nature of the feedback system. Also as I say that A and beta can be positive or negative ok.

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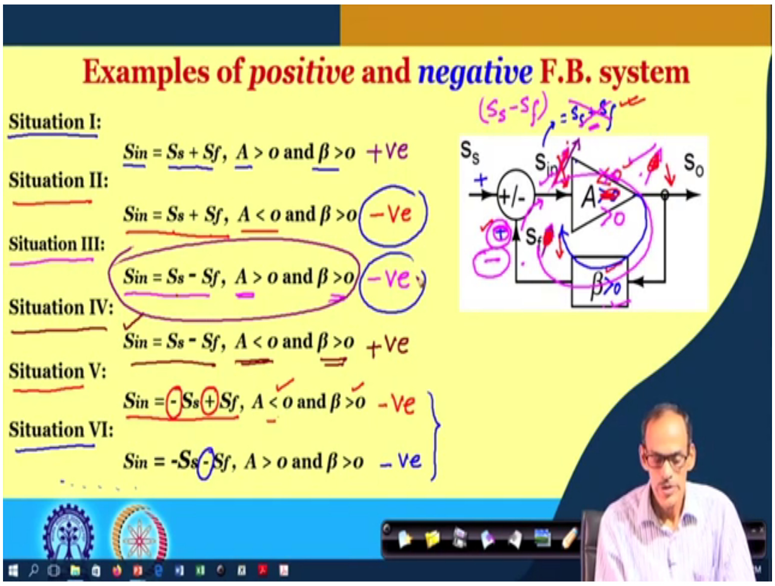

So, let us see, what are the different possible options, it is not all exhaustive options but just to tell you some of the examples to clear your concept. Let you consider a situation I where s in equals to S s plus S f which means that I do have plus sign here and plus sign here. So, that gives us S in equals to S s plus S f. And if I consider both A and beta they are positive and then as I said that if I am having this situation, if I consider any change within this loop suppose, this is increasing and because of plus sign this is increasing and again this is plus sign or beta is positive. So, this S f it is increasing.

Now, I do have plus sign here or I do have plus sign here in the expression of S in. So, the effect coming back here due to this change it is in the same direction. So, that means, the feedback system here it is positive. On the other hand, if I consider situation II. So, I do have say situation II, where S in equal to S s and S f; that means, we are retaining this one, but if I consider A is negative. So, if I consider this A it is negative.

Then, you can easily see that the original change here, if this is the original change because this is negative. So, instead of going positive direction this will be in the negative direction since beta is positive. So, now, it will be negative and I do have a plus sign here. So, on this change it is coming back here in this direction. So, since the original change and the feedbacks effect they are opposing each other or the feedback signal it is negating the original change.

And hence the feedback system it is negative feedback system. So, likewise if I having say this situation, where S in it is S s minus S S f. So, instead of saying that this is S s plus S f let me say this is S s minus S f and if I consider both of them are positive. So, this is positive this is also positive and you yourself can find that since this is minus sign here while the signal it is going through this loop from here to here they are in phase again here to here they are in phase.

But whenever the signal is going from this port to this port because of this minus sign it will be creating an effect which is countering the original change and hence this is negative feedback system. So, likewise you can see the situation IV where we are retaining this same expression, but then this is negative and this is positive. So, you yourself can find that this is positive feedback.

So, likewise if I consider situation V where the expression of S in it is different and this is negative and this is positive. And it can be again it can be shown that I do have minus sign here, but I do not have minus sign here this is plus sign. So, this is again negative note that here I do have minus sign, but it is not having any impact on the definition of negative feedback system. So, likewise you do you also have the other case in this situation and you yourself can find then this is negative mainly because we do have minus sign here.

So, likewise we do have many other situations and you yourself can find when the system it is positive feedback or negative feedback. Note that while we are making this change original change and, we are trying to see the effect, we are giving sufficient time to see the corresponding steady state change. So, this definition of this positive and negative feedback system it is primarily based on observation of negative sorry steady state response.

So, on the other hand instantaneous response it may vary, but then without having any ambiguity, we prefer to use this steady state change to define whether the system it is positive feedback or negative feedback. So, what I like to say that whatever the negative feedback system we are talking about say here or here or maybe here, this does not give any guarantee that the system it will remain a remain negative feedback for all possible transient situation.

So, anyway we will be discussing that later, we will we will come back, but right now at least it is clear that what is called positive feedback system and negative feedback system. Now, instead of considering all possible situation without loss of generality, we may consider say this situation and we will continue our discussion, which means that as I said that we will continue with this situation namely this is the minus and this is plus which means that S in equals to S s minus S f

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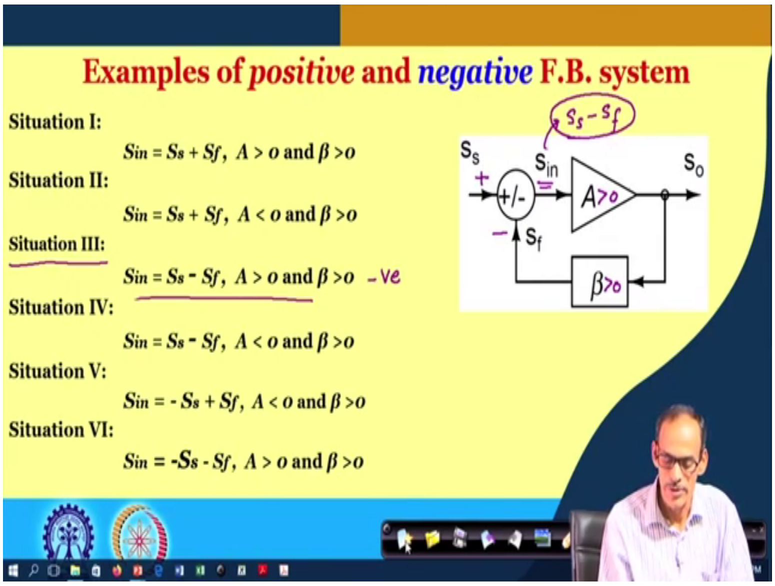

And unless otherwise it is stated, we assume that this is plus and this is minus sorry this is both are plus. And hence this is negative feedback system, but of course, this polarity we may not change, but we have to keep in mind depending on the situation we may change it. So, in our further discussion, we may consider S in equals to S s minus S f.

And then, we will be moving for further analysis particularly input to output transfer function.

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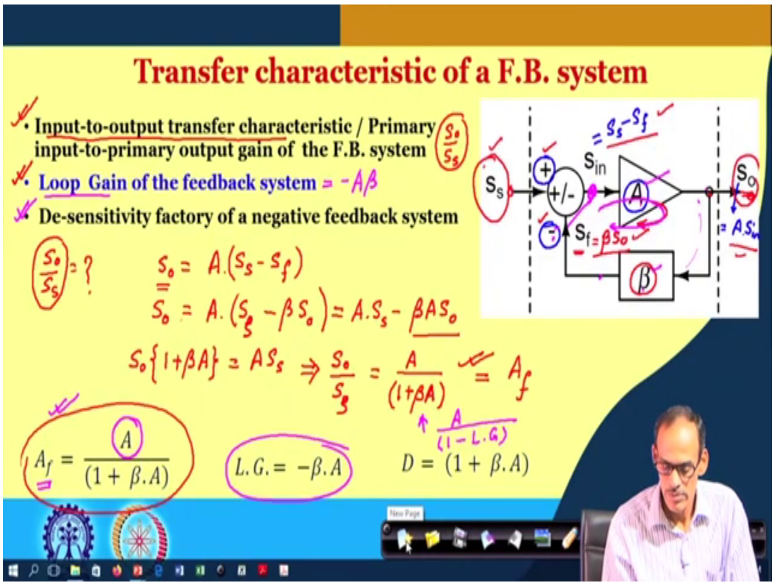

So, in the next slide, we are going to talk about transfer characteristic of the feedback system. So, as I said that we may have different situation, but without loss of generality, let we consider that primary port, it is having plus sign at the mixer terminal and the feedback signal terminal it is having minus sign which means that this S in equals to S s minus S f.

On the other hand since, it is forward amplifier and we know its transfer function it is A. So, we can say that S o so, this S o equals to A times S in. Likewise, when you consider say signal whatever the signal we do have S o, it is generating S f and we do have a transfer function of the feedback path it is beta which means that S f equals to beta into S o.

So, we do have three equations here and here. And if I consider that this is my primary input port and this is the primary output port. And I like to know what will be the transfer function of this entire system, starting from this primary input to the primary output. So, input to output transfer characteristic if I say, which means that S o divided by S s. So, what is the transfer function when we do have the feedback system in place and assuming that the polarity of this terminal it is positive and here it is negative.

So, if you consider say this equation this equation and this equation, we can get the expression of S o divided by S s. So, to start with we do have a S in is this one. So, S in it is given here. So, we can say that So equals to A times S in and S in is S s minus S f and then S f equals to this S o times beta. So, we can see that this is S f equals to A into S o minus beta into sorry this is S s minus beta into S o. Since, we need to find this ratio. So, we are getting relationship between S s and S o. o that is what we obtain. So, we can further expand it. So, this is A naught or other A into S s minus beta into A into S o and then this S o part we can bring it on the left side. So, we can get S o equal multiplied by 1 plus beta into A equals to A into S s.

In fact, that gives us the required input to output transfer characteristic S o my by S s equals to A divided by 1 plus beta into A. So, that is the input to output transfer characteristic of the feedback system. This expression we will be frequently using and this is defined as input to output transfer characteristic of the feedback system. So, that is what I have written here. So, likewise you can also find the other important transfer characteristic I should say internal transfer characteristic which is referred as loop gain.

If you see it carefully and if you go through this loop, it is having its own gain. So, if I start from any point in this loop and if I try to find what will be the net transfer function and so, if say for example, if I start from here and if I go from this point to this point I do have a transfer function of A and then through this path I do have beta. So, from here to here I do have transfer function A into beta.

And then again going from this point to this point here to here I do have a minus sign. So, we can say that this loop gain; this loop gain of the feedback system it is A into beta and also we do have a minus sign. So, the loop gain of the system it is minus A into beta. In fact, A f if you see here you may write this one as A divide by 1 minus loop gain. So, if you see it here carefully that apart from this loop gain also there is another important factor called desensitization factor.

What is what does it mean is that, if you look into this transfer function of the feedback system and on the other hand, if you see the transfer function of the forward amplifier ok. Let me clear the board and then I will explain yeah. So, what I said is that, if I do not have this feedback path if I remove this one and if I consider this is the primary input and this is the primary output.

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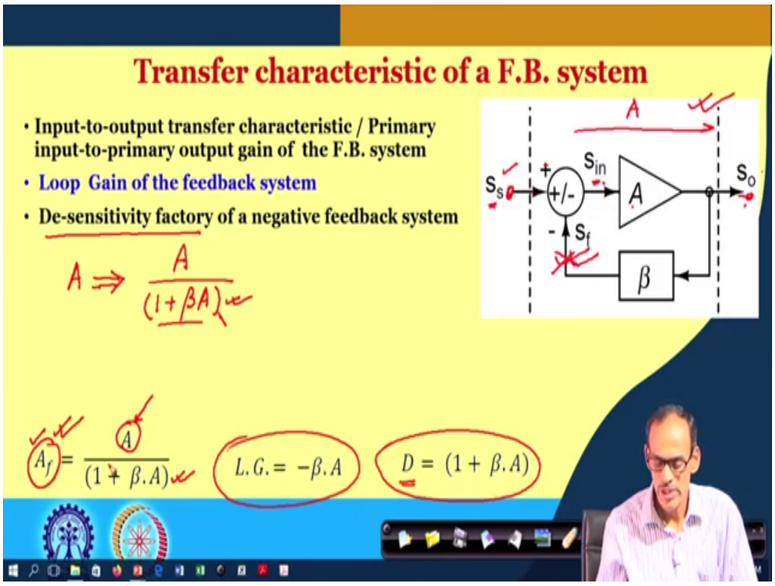

So, from here to here the transfer function it is we do have plus here. So, if I remove this S f S in is equal to S s and hence So is equal to A times a S in incidentally that is same S s. So, the forward path amplifier gain it is A. Now, if I if I incorporate this feedback, you now if I incorporate this feedback whatever the transfer function I am getting it is A f. So, the gain of the system it is getting changed from A to A divided by 1 plus beta into A.

In other words we can say that, the system gain it is getting reduced by this factor or we may say that circuit is getting desensitized by this factor. So, this factor it is referred as d sensitivity factor of this negative feedback system. In fact, here we said it is the feedback system gain it is changing by A factor of 1 plus beta into A.

Later we will see that this factor it is not only changing the gain by this factor but, also it is changing the input resistance output resistance for that matter sensitivity of the circuit it is getting change by this factor. And hence in general this 1 plus beta into A it is referred as de sensitivity factor D ok.

So, whenever we will be talking about any negative feedback system, we may always refer to this four important parameter; one is forward amplifier gain, another one it is the loop gain then de sensitivity factor and of course, the gain of the entire feedback system. Now we need to be careful in this model that what are the assumptions we are doing and also we need to be aware that this analysis of this feedback system or I should say this model it is very generic it can be deployed in different systems. So, first let us try to see what is the applicability of this analysis namely, A f equals to A divided by 1 plus beta into A.

And then we will be talking about what are the assumptions, we are making here and when those assumptions are you know practically valid or not.

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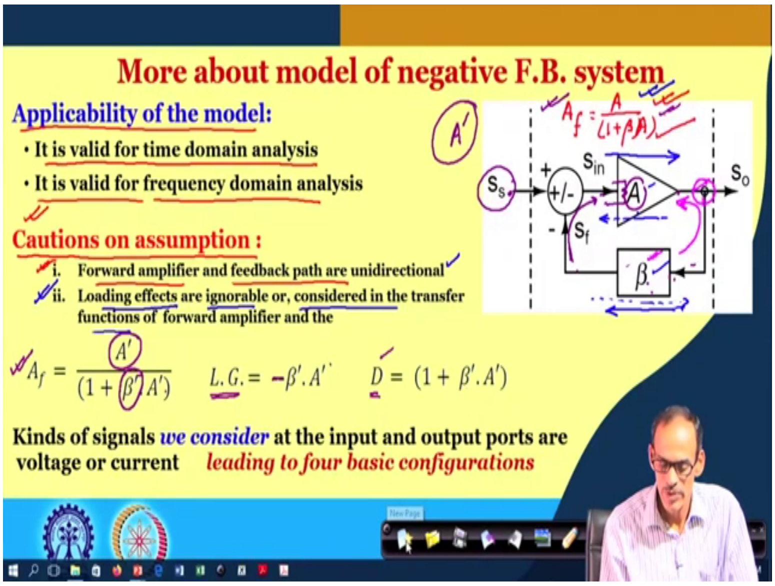

So, the as I said that applicability of this this model this model and whatever we see A f equals to A divided by 1 plus beta into A. In fact, whatever we have discussed it is valid for the signal in time domain.

So, for time domain analysis, we may use this model and we can make use of this formula. This is also valid for frequency domain analysis. So, as long as in the system it is linear and time invariant, we can make use of this formula. So, as I said that this is very generic, but of course, if the system it is non-linear we cannot deploy directly then we have to see up to what extent it is useful.

But then as I said that we need to be very careful of what are the assumptions we are making. We need to be whenever we will be deploying this model in a practical circuit, we need to be aware of that. First of all the forward amplifier and feedback path they are unidirectional which means that we assume that signal it is propagating from left to right through this forward amplifier.

And the through the feedback path on the other hand the signal it is going from right to left. So, in case the signal it is also propagating in this direction then we have to make the corresponding correction. So, likewise in case if the signal some part of the signal if it is having a chance to propagate from right to left through this amplifier then also we have to take the necessary correction.

So, in this the formula, we have assume that both the amplifier forward amplifier and then feedback path they are unidirectional. The second assumption we need to be careful it is the loading effects. So, we are considering that loading effects either ignorable or probably they are considered in the transfer function. What do I mean by that is that.

Whenever we are say sampling the signal from this point and we are feeding the signal to this feedback network naturally, this output port it is getting loaded by input impedance or input condition of the feedback network. So, we are probably ignoring this loading effect or we have to capture that loading effect in this formula. So, likewise, whenever we do have the feedback network having a transfer function of beta from here to here.

And then once you are connecting this output to the input port along with the primary source, whatever the loading effect it may be coming from the input characteristic of the amplifier and or the impedance of the signal source, we are assuming that is already considered. Unless that is properly taken care you may get erroneous result. So, if I typically what it is done here is instead of calling this is A, we may call it is A dashed and we assume that A dashed represents the forward amplifier gain after considering the loading effect from the feedback network.

So, we call instead of A, we call it is a dash. Likewise, beta the feedback path or feedback networks transfer function beta instead of beta we consider beta dash which incorporates the loading effect. So, if you take care of those loading effects of course, then this equation it will be getting change in this form, where A need to be replaced by A dashed and beta need to be replaced by beta dash.

Likewise the loop gain we do have minus sign and then beta dash and A dash and then also the de sensitivity factor which is 1 plus beta dashed into A dashed right. So, while we will be deploying this as I said while we will be deploying this formula, we need to be careful now next thing is that whatever the signal we are talking about signal at this point signal at say this point.

So, far we are talking about their signal. Now, this signals they can be voltage current or for that matter any other say for example, temperature pressure whatever it is. So, this model it is in fact, generic enough to capture various situation as long as we map our original system or practical system into this model. Then we can make use of whatever the formula we will be, we have derived as well as we will be discussing.

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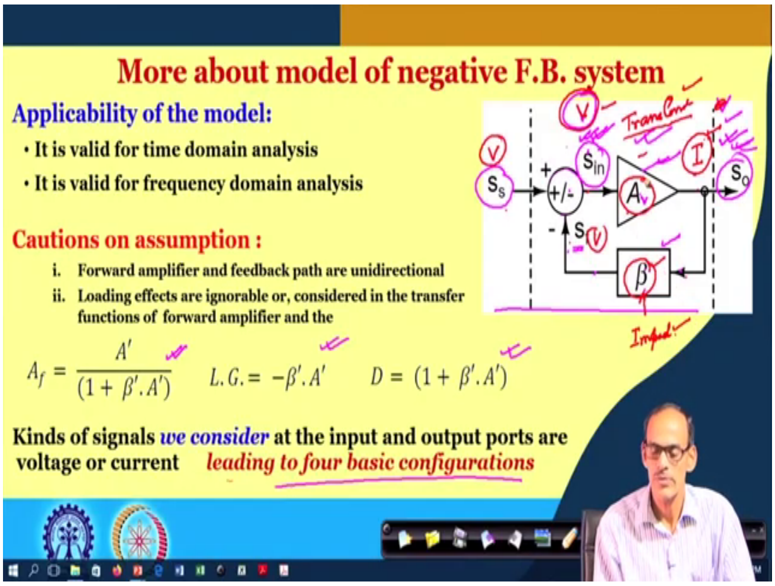

But, first of all we need to be careful that the in our discussion of this analog electronics, we will be considering this signals this signal this signal having two types either they can be voltage or current.

So, that is the assumption and it is not mandatory that the signal here and here should be of same type say for example, this may be voltage this may be current and so and so. So, we do have four different possible situation; leading to four basic configurations. So, depending on the signal type here and signal type here, we will be having four basic configuration out of this this model.

And only thing is we need to be careful that if we, if we define say this signal nature, then that should be supported by the amplifier and also whatever the signal it is coming to this mixer need to be consistent with that signal time. Same thing whenever, we are talking about the signal here we should be careful that the this block as well as this block it is they are characterized based on the signal type.

So, if I say this is voltage and if I say this is also voltage. So, A is the voltage gain and this is expecting to generate voltage. So, this is also converting voltage to voltage. On the other hand, in case if say this is voltage, but say this is current. So, then this this block it is converting voltage to current which means this should be transconductance. So, then A should be transconductance which receives a voltage and converts the signal in the form of current.

Now, if you consider here, it takes the signal in the form of current and it is it is suppose to produce a voltage here. So, that the mixer will be having appropriate conversion there, without really transferring it. So, if this is transconductance then this beta should be impedance or resistance. And if this is voltage this is voltage this should also be voltage. So, then only this two voltage you can mix.

So, based on the situation based on different types of signals the unit of the transfer function should; should be appropriately modified. So, it may be unitless or it may be transconductance or trans impedance or vice versa. So, we will be talking about four basic configurations, but before that let me take a short break and then we will be coming back.